The HOA library, review and prospects

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ABSTRACT

In this paper, we present the HOA Library, an open source high order ambisonic spatialisation tools collection programmed in C++. We expose the objectives and characteristics of the project, which treat the potential of high order Ambisonics in a musical perspective, based on the practice and the creativity of the electronic musicians. We clarify the context of use, the choice of optimization and decoding. We review the implementations of the library in various environments, such Max, Pure Data, and Faust. We discuss the use of feedback from musicians and members of especially Max and Pure Data community. Finally, we advance the prospects of the HOA library in its current developments in three-dimensions.

1. INTRODUCTION

Initiated in 2012 by the CICM, Centre for research in Computer Science and Musical Creation of the University Paris 8[1], within the framework of the LABEX arts H2H[2], the HOA library project aims to provide musicians access to immersive spatialized sound through the techniques of high order Ambisonics using accessible technologies and devices within the medium of computer music. The HOA library is free and open source, and is available for Max, Pure Data and FAUST on multiple platforms[3]. In the following article, we will discuss the HOA library approach, its specific treatments, its implementations, the uses and the prospects of 3-D spatialisation.

2. THE GOAL AND THE SPECIFICITIES OF THE PROJECT

The HOA project aims to provide spatialisation tools based on high order Ambisonics to musicians and composers. This artistic domain approach has driven our research around two axes: the development of new functions of sound and space manipulation relevant to composition and musical context, and the adaptation of the spatialisation tools to many uses and various restitution systems such as quadraphonic, 5.1 surround or binaural.

[1]http://cicm.mshparisnord.org/
[2]http://www.labex-arts-h2h.fr/

2.1 The approaches of sound field synthesis and transformation

In Ambisonics, the processing of circular harmonics involves basically straightforward gain operations that allow simulation of the position of point sources or the application of transformations across the sound field – such as rotation. In our framework, however, we consider the possibility of manipulating these harmonics in an experimental way by using well-known treatments in order to use sound space as an expressive dimension of music and sonic design.

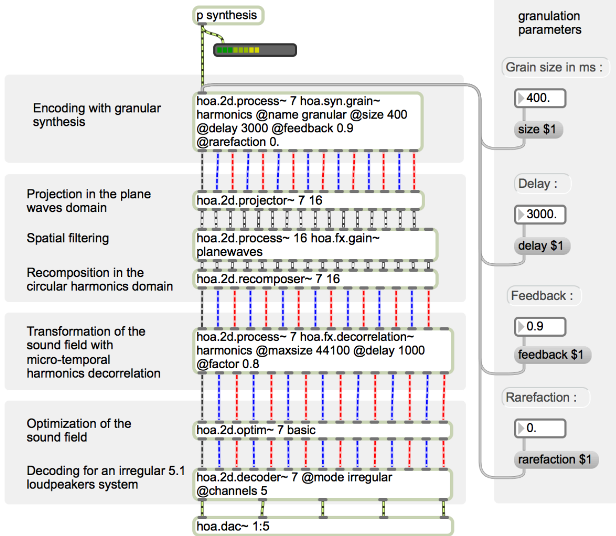

Figure 1. Representation of an ambisonic DSP chain in the Max implementation of the HOA library.

2.1.1 Circular harmonics synthesis

Beyond the "classical" approach of the point source synthesis attainable with standard ambisonic encoding, we focus to extend the diffuse sound field[4] synthesis techniques [1, 2] by implementing audio processing to directly synthesize circular harmonics. We therefore offer implementation of granular synthesis, ring modulation, time-delay or frequency filtering as new encoding tools. This approach combines the characteristics of the particular representation of space found in Ambisonics with the

[4] A diffuse sound field is, for the listener, a space where sounds seem to arrive from all directions, like the late reflections of a reverberation.

characteristics of the synthesis techniques used, resulting in original and creative sound fields. As an essential element of this implementation lies in the combined control of sound and spatial qualities, we explored several techniques, trying to find parameters capable of managing both of these aspects. For example, the delay implementation allows controlling a diffusion variable that defines the delay-time of each harmonic according to its index and the decomposition order. The variation of this parameter clearly affects the sound quality, but also the distribution of sound within the space that could vary from almost directional to extremely chaotic. Another example with granular synthesis, the decay and the size of the grains can be managed according to the index and the order of the harmonics to give the sensation that small grains are far away and persist in time in opposition to the larger grains that seems close, nearly omnidirectional, and that have a fast decay time. These examples contribute to demonstrate how spatialisation can be a constitutive dimension of musical sound.

2.1.2 Circular harmonics transformation

In a similar way, we assert that a lot of musical techniques can be explored to change the qualities of a sound field. We experimented with several treatments like reverberation[5], fractional order simulation, spectral filtering or delay lines, controlling the sound field diffusion in order to offer new sound field manipulation parameters. Another important point is the ability to project the sound field in the plane waves domain to access a new processing domain and new treatments and then to recompose it to the circular harmonics domain. The projection allows applying local changes. The spatial filtering, for example, reduces or increments the sound level of a part of the sound field. Again, we offer the possibility to implement many other forms of processing that bring completely different renderings than their implementation in the circular harmonics domain (time-delay, frequency filtering or shifting, etc.). Furthermore, re-composition of the circular harmonics domain provides specific operations, in particular, sound field distortion that compresses or expands the sound field and that can be compared to the visual fisheye effect [4]. Thereby, the HOA project provides new musical perspectives of sound spatialisation by exploring Ambisonics from a more artistic point of view, freed from a realistic approach to sound space.

2.2 The adaptation to several uses and various restitution systems

High order Ambisonics has often been complicated to use, due to the necessity of a large and optimal loudspeakers system. Consequently, in the last couple of years, the decoding and the optimization of ambisonic sound fields were among of the main subjects of research. Nevertheless, the solutions offered until now only work for specific loudspeaker configurations and for a fixed decomposition order. Within the framework of the HOA project, we want to provide the possibility to use Ambisonics with many different loudspeakers configurations and for any order of decomposition. This approach is essential in order to ensure that composers and musicians will be able to use these techniques in multiple situations – given the fact that most loudspeaker systems are not optimal for Ambisonics – and in various audience arrangements.

2.2.1 Optimization

The principal constraint of our approach is the fact that we don't only synthesize point source but also diffuse sound fields, and these techniques do not require the same restitution processing. Indeed, the most commonly used optimizations are efficient for point source synthesis but deteriorate the diffuse sound fields. Thus, we needed to propose tools corresponding to our restrictions. We decided to give to the user the choice to apply or not two optimizations, "max-re" [5] and "in-phase" [6], before decoding. Theses possibilities allow the sound field restitution to adapt to several configurations – a listener ideally placed at the center of the loudspeaker arrangement, an audience confined to the center of the restitution area or an audience that covers all of the restitution area. Furthermore, this approach is adapted to the sound field characteristics, diffused or composed by point sources.

2.2.2 Decoding

The decoding operation has been considered for three cases. First, we offer a decoder for an optimal restitution system, a set of loudspeakers equally spaced on a circle. Binaural decoding has been implemented to enable headphone restitution. For this technique we take advantage of Ambisonics to optimize the processing that allows reaching up to high orders, even on a personal computer [4]. It can be very useful during the composition process where the user doesn't have access to a large set of loudspeakers, or for a musical installation. The last decoding tries to make up the artifacts due to an irregular array of loudspeakers. The most common choice is to use fractional order simulation [7], but here again, this processing greatly degrades the restitution of the diffuse sound field. Thus, we implement an algorithm that combines ambisonic decoding and standard panning to offset the missing loudspeakers [8]. With this technique we can go up to any high order and adapt the decoding to many loudspeaker configurations. We made tests for stereophonics, quadraphonic, 5.1 and 7.1 loudspeaker systems and other more eclectic configurations at several decomposition orders with good perceptual results[6].

[5] The reverberations use the Freeverb algorithm developed by "Jezar at Dreampoint" or the Gardner's zero latency convolution [3].

[6] As the possibilities of the systems are infinite it is difficult to quantify the results objectively.

3. THE IMPLEMENTATIONS

HOA library is primarily a set of C++ modular classes created to allow for portability and deployment on multiple platforms within several software environments. The processing classes inherit from two main classes, *Ambisonic* and *Planewaves*, depending on the domain for which they are destined. For example, the *Encoder* class belongs to the ambisonic domain and the *Decoder* classes belong to both of the ambisonic and the plane waves domains. Moreover, the library provides classes, independent of any software platform, managing the behaviors of graphical user interfaces and helping to their creation.

Providing a set of easily portable code functions across multiple operating systems poses some technical problems. Indeed, higher order Ambisonics requires a large amount of parallel processing that necessitates optimizations in order to work on most personal computers. We therefore use the free and open multiplatform library cBlas[7], particularly suitable for digital signal processing in our context. An obvious example of this use is the implementation of the binaural decoding, impossible to achieve for personal computers without optimization of the matrix calculations [4]. The deployments are currently available for Max and Pure Data. We are also working on the implementation of Csound opcodes and a VST plugin. In parallel, we carried out a version the library in the Faust language that offers many advantages [9].

3.1 Deployment for Max and Pure Data

The first implementation of the HOA library was made for the Max environment and then for Pure Data. Besides the fact that these programs are used by a large community of musicians and composers, this choice was motivated by their modular approaches that offer ideal realms for prototyping, experimentation and creation of new treatments during the development phase of the library.

3.1.1 The CICM Wrapper for PD

While our first implementation for Max software was relatively easy, thanks to an API very well suited to our needs, both for the development of multichannel processing and for the creation of graphical interfaces, many complications appeared during implementations for Pure Data. These difficulties required us to rethink the structure and the overall functioning of graphical objects and signal processing objects in Pure Data. Thus, these particularities led us to the creation of an API in C and Tcl / Tk: the CICM Wrapper[8] [10]. This set of codes that provides new features and facilitates the implementation of objects, now offers the possibility to develop the Max and the Pure Data implementations in parallel[9].

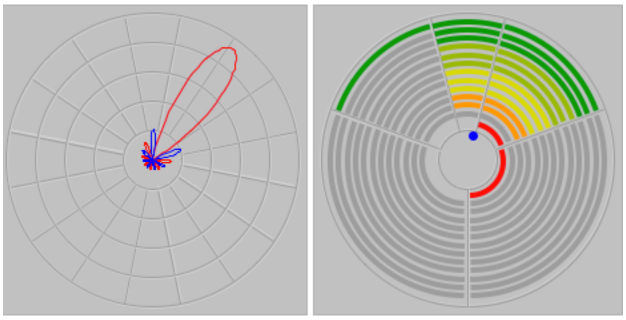

Figure 2. From left to right: hoa.scope~ object and hoa.meter~ object in Pure Data.

3.1.2 DSP objects

Concretely these implementations include a set of external boxes for ambisonic digital processing. The three main objects allow encoding a signal in the circular harmonics domain with or without distance compensation, and decoding the ambisonic sound field for several loudspeaker configurations as well as for headphones (hoa.encoder~, hoa.map~ and hoa.decoder~). Then we offer externals for sound field transformation such as rotation (hoa.rotate~), optimization (hoa.optim~), and simulation of fractional order (hoa.wider~). Finally, the library contains externals to project the sound field in the plane waves domain and to recompose it in the circular harmonics domain leaving room for many treatments (hoa.projector~ and hoa.recomposer~).

3.1.3 GUI objects

Another important part of the HOA library involves facilitating the comprehension and the appropriation of the processing by use of original graphical interfaces.

The scope (hoa.scope~) is a kind of ambisonic phase meter that provides a representation of the sound field as the sum of the circular harmonics, see **Figure 2**. It is a useful tool to understand the circular harmonics decomposition and the effects of the several treatments applied to the sound field. We also offer a circular multichannel meter (hoa.meter~) that is very useful to visualize the sound field restitution and to quantify the degradation thanks to the representation of the velocity and energy vector, see **Figure 2**.

As manipulation of the sound field in the ambisonics domain can induce complexity due the great number of parameters to control, we provide a graphical user interface that represents the field as set of points on a plane that can be useful to manage the gains of a spatial filter (hoa.space), see **Figure 3**. In a similar way, another interface that displays virtual microphones can be used in combination with the recomposition external to set up effects like sound field expansion and retraction

[7]http://www.netlib.org/blas/

[8]The CICM Wrapper is available at the online repository: https://github.com/CICM/CicmWrapper.

[9]Far from being restricted to the context of ambisonic interfaces, this work is open to more common uses and helped to achieve a set of graphical interfaces in Pure Data with a high ergonomic potential.

(hoa.recomposer), see **Figure 3**. To conclude the GUI part, the HOA library integrates an editor of trajectories, that should be used in association with the encoder external with distance compensation and that allows temporal management of spatial positions of a set of point sources in a two-dimensional space (hoa.map), see **Figure 3**.

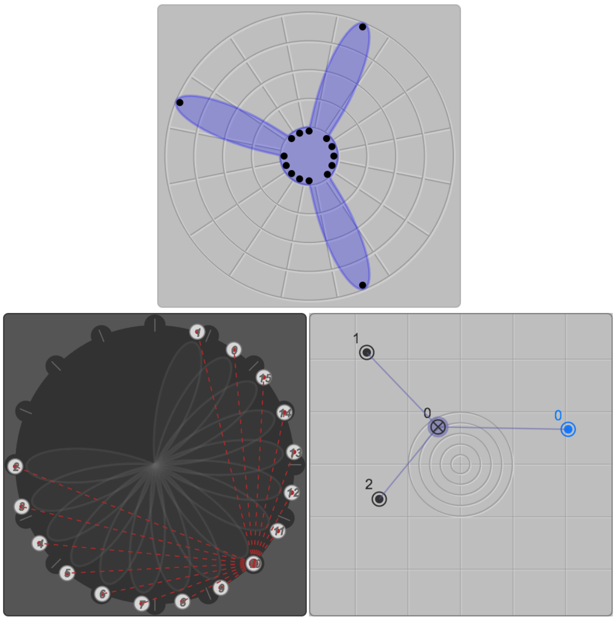

Figure 3. Graphical user interfaces in Max implementation. From left to right: hoa.space, hoa.recomposer, hoa.map.

3.1.4 Utility tools

The HOA library also integrates a set of tools to facilitate the creation of multichannel treatments and improve the ergonomics of the software environment, such as an ability to automatically connect HOA objects together (hoa.connect), and an object that allows multiple instantiations of the same treatment in the circular harmonics domain depending on the order of decomposition, or in the plane waves domain depending on the number of channels (hoa.process~). Such objects are very useful to factorize the set up of the parameters and have enabled us to produce and to test relevant sound processing in the field of circular harmonics such as granulation, amplitude modulation or the micro-temporal decorrelation that would have been far more laborious to implement without it.

3.2 Deployment for FAUST

Following the first version of the HOA library, the research team of GRAME[10] and CICM studied the possibility of porting the C++ library to FAUST language[11]. This undertaking was successful and resulted in the HOA library in FAUST language, which is already available in the public distribution. Thus, it is possible to perform all basic treatments such as encoding, decoding, fractional order simulation, distance compensation and optimizations of the sound field in this language that offers many advantages. FAUST language and its compiler are free and open and used to compile codes for a diverse range of operating systems such as Windows, Mac OS, Linux, Android or Raspberry [11]. It offers, in addition, the possibility of compiling treatments for a large number of software platforms such as Supercollider, Csound or as standalone applications such as JackAudio or Qt.

The functional syntax of FAUST produces a clear and concise code highlighting the mathematical operations underlying the Ambisonics. With this particular syntax, the sequence of treatments is facilitated; a few words are enough to create a complete chain of processing. The compiler generates further diagrams [12] and a mathematical documentation of transactions, providing a degree of continuity in understanding the treatments implemented [13]. More, through the compiler and compiler interfaces, treatments become highly portable for many software environments and operating systems. Through the simplicity of compilation, we can take advantage of applications where the processing chain and order decomposition are fixed. With this feature, the compiler associated with the FAUST language optimizes the code and provides much more efficient applications in many implementations [14].

The HOA FAUST library also offers the possibility of producing stereo decoding and rotation of the sound field. We can consider leveraging new implementations including many treatments already available in this language, as Freeverb or summaries of STK library FAUST [15], adapting to ambisonic fields. Note however that the FAUST language is not suitable for some operations such as file upload or Fourier transforms, preventing some implementations such as convolution reverb or binaural decoding.

4. ASSESSMENT

Since 2012, the HOA library has been used in the framework of musical creation projects in live electronic composition workshops at the music department of university of Paris 8 and for several demonstrations. These tests in creation contexts have allowed us to receive user feedback about this new library. These applications, that have mainly employed a 3rd to 7th ambisonic order for 8 to 16 loudspeakers, proved the adequacy of the library to the needs and the creativity of the composers and the practical production constraints. Furthermore, the Max and the Pure Data communities also provided useful feedback that drove our research. After two years, we can now consider the library and its uses in a more objective view.

During the project, we discovered and created new sound field treatments, such as granulation, time-delay or spatial filtering, that seem to be one of the main attractive features of the HOA library. Of course, the treatments included in the distributions are mainly examples and we invite the users to invent and create their own. We know that synthesis and transformation in the circular harmonics domain become very complex notions for the musician. It could have been straightforward to provide a system where the complexity of the processing is hidden. Nevertheless, we would have lost in flexibility and the

[10] http://www.grame.fr/

[11] http://faust.grame.fr/

operations in play would have been opaque. Furthermore, the graphical user interfaces, the ergonomic tools and utilities that allow an easy management of the treatments, has made the key concepts and audio processing of Ambisonics understandable for users; contributing to the accessibility of the library. Another important point is the optimization of the audio processing that permits the library to be accessible for a large community of composers and musicians. Indeed, the optimization allows setting up complex and expensive processing, like binaural rendering, with the use of high order decomposition on many computers and for various digital signal processing systems.

5. THE 3D VERSION

The other direction that we are investigating is the adaptation of the library for three-dimensional restitution. In the framework of this new objective, we keep on performing our research in a creation field with the goal of providing a library that will work with heterogeneous loudspeaker systems with high order Ambisonics. This undertaking involves several aspects.

5.1 Technical aspects of the audio processing

The main aspect is the adaptation of the audio processing available in the current version of the library for a three-dimensional representation of the sound field. The implementation of the mathematical algorithms used in Ambisonics is relatively straightforward, especially for the encoding and the regular decoding, but some difficulties lie in the adaptation for concrete situations. Indeed, the spherical harmonics projection requires a perfect discretization of the sphere; but this is only possible with the platonic solids[12]. Thus, these particularities constrain the order of decomposition to a maximum of three and cause difficulties in establishing loudspeaker arrangements in common situations. Concretely, this prevents a lot of processing such as an optimal projection in the plane waves domain, binaural rendering or irregular decoding. In this way, it becomes necessary to find an algorithm to discretize a sphere that matches our needs and doesn't generate too many artifacts. Another important point in adapting the audio processing is to find the normalization of the spherical harmonics for our musical approach. Indeed, our uses of harmonics, especially through multiple forms of synthesis and transformation specific to the project, necessitate signals normalized between -1 and 1 – different from the usual implementations.

5.2 The graphical representations and interactions

The three-dimensional context brings up several issues about the graphical representation of the space and how to interact with it. There are mainly two ways to display the space, as a set of bi-dimensional cross-sections or with depth representation.

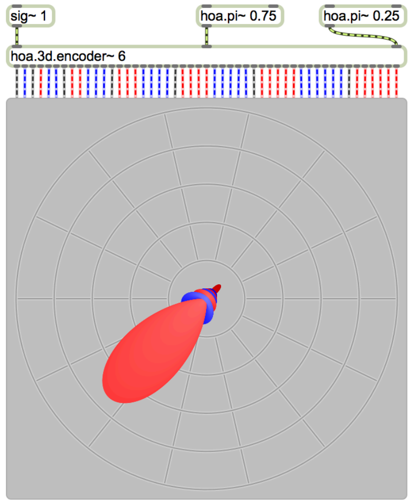

Figure 4. Three-dimensional representation of the encoding of a Dirac.

For the interfaces that allow visualization of the sound field as either a sum of spherical harmonics, see **Figure 4**, or as a set of peak level meters of loudspeakers, it seems preferable to choose this last solution because it offers a much better way to comprehend three-dimensional space. For the interaction and control interfaces, such as the editor of sources trajectories, the first solution seems, for the moment, to be the better way to proceed. Actually, a set of bi-dimensional cross-sections allows an easy access to each dimension and is preferable for use with common interfaces like the computer mouse and tactile tablets.

5.3 Tests and material aspect

As we already noticed, the minimal configuration for three-dimensional rendering is less attainable due to the important space necessities and the difficulties of realizing a coherent loudspeaker arrangement. Within the walls of the CICM and the University Paris 8, all the tests are made with a cube of loudspeakers that allows us only the first order of decomposition and with an irregular 16 loudspeakers configuration. Nevertheless, we also take advantage of the binaural rendering to investigate the possibilities of the third dimension and its use with high orders. A first version of the library in 3D is available since july 2014.

Finally, thanks to partnership with the ZKM[13], and the faculty of music of the University of Montréal[14], we will be able to test the implementations with other loudspeaker configurations, a hemisphere of forty-three loudspeakers at the ZKM and a hemisphere of thirty-two loudspeakers at the University of Montréal, and thus reach

[12] There are only five platonic solids (tetrahedron, cube, octahedron, dodecahedron, icosahedron).

[13] The Zentrum für Künst und Musik (center for art and music) in Germany. http://www.zkm.de/.

[14] http://www.musique.umontreal.ca/.

high orders of decomposition.

6. CONCLUSIONS

In this paper, we presented the HOA Library, the objectives and characteristics of the project, which treat the potential of high order Ambisonics in a sharp musical perspective, based on the practice and the creativity of the electronic musicians. We have clarified the context of use, the choice of optimization and decoding. We reviewed the implementations of the library in C++ in various environments, such Max, Pure Data, and Faust, involving the use of CICM Wrapper for Pd. We discussed the use of feedback from musicians and members of especially Max and Pure Data community. Finally, we have advanced the advances and the prospects of the HOA library in its current developments in three-dimensions. To conclude, we could say that one of the best features of the HOA library consists in its open source code in C++ and all of its online documentation[15], in order to ensure a long-term accessibility by the community of the users, musicians and programmers interested in such an approach of spatialisation.

Acknowledgments

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7. REFERENCES

[1] G. Wakefield, “Third-order Ambisonic extension for Max/MSP with musical applications”, in *Proc. International Computer music conference*, New Orleans, 2006, pp.123-126.

[2] J. Daniel, R. Nicol, S. Moreau, “Further investigations of high order Ambisonics and Wavefield synthesis for holophonic sound imaging”, in *Proc. Audio Engineering Society 114th International convention*, Amsterdam, 2003.

[3] W. Gardner, “Efficient convolution without input-output latency”, in *Journal Audio Engineering Society*, vol. 43, 1993.

[4] J. Colafrancesco, P. Guillot, E. Paris, A. Sèdes, A. Bonardi, “La bibliothèque Hoa, bilan et perspectives”, in *Proc. Of Journées d’Informatique Musicale*, Saint-Denis, 2013, pp.189-197.

[5] M. Gerzon, “General metatheorie of auditory localization”, in *Audio Engineering Society Preprint*, 1992.

[6] D. Malham, “Experience with large area 3-D ambisonic sound system”, in *Proc. Institute of Acoustics*, vol. 14, part. 5, 1992, pp.209-216.

[7] M. Neukom, “Ambisonic panning”, in *Proc. Audio Engineering Society 123rd International convention*, New York, 2007.

[8] P. Guillot, *Les traitements musicaux en ambisonie*, Master’s Thesis, Université Paris 8, 2013.

[9] P. Guillot, E. Paris, M. Deneu “La bibliothèque Hoa pour Max/MSP, Pure Data, VST, FAUST…”, in *Revue Francophone d’Informatique Musicale*, vol. 3, Saint-Denis, 2013.

[10] P. Guillot, “Une nouvelle approche des objets graphiques et interfaces utilisateurs dans Pure Data”, in *Proc. Journées d’Informatique Musicale*, Bourges, 2014.

[11] S. Letz, D. Fober, Y. Orlarey, “Comment embarquer le compilateur FAUST dans vos applications”, in *Proc. Journées d’Informatique Musicale*, Saint-Denis, 2013, pp.137-140.

[12] Y. Orlarey, D. Fober, S. Letz, “An algebraic approach to block diagram constructions”, in *Proc. Journées d’Informatique Musicale*, Marseilles, 2002.

[13] K. Barkati, Y. Orlarey, J. Barthélemy “Abstraction du processus temps reel : une stratégie pour la preservation à long terme”, in *Revue Francophone d’Informatique Musicale*, vol. 2, Saint-Denis, 2012.

[14] Y. Orlarey, D. Fober, S. Letz, “Adding automatic parallelization to FAUST”, in *Linux Audio Conference*, Parma, 2009.

[15] R. Michon, J. O. Smith, “FAUST-STK: a set of linear and non linear physical models for the FAUST programming language”, in *Proc. Digital Audio Effects*, Paris, 2011.

[15] The library is released under the terms of the GPL, https://www.gnu.org/. The sources and the documentation are available online on the project repository: https://github.com/CICM/HoaLibrary/